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**MEASURING METHOD FOR RECORDING AND  
EVALUATING PHOTOGRAMS OF MOVING SURFACES**

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## **BACKGROUND OF THE INVENTION**

### **Field of the Invention**

This invention relates to a measuring method for taking and evaluating line images of moving surfaces, such as obtained by interferometry or line projection, and wherein the movement has a translatory and/or a rotatory displacement portion and/or a deformation portion.

### **Description of Related Art**

Measuring methods of "holographic interferometry", "electronic speckle pattern interferometry (ESPI)" and "line projection" are often used for showing deformations of surfaces. Here, the deformations can be recognized by the number and shape of the interference lines in the image. The position of these lines is displaced by the change of the deformations. With chronologically changing surface forms, the lines are displaced at the corresponding speed. If under these conditions a picture is taken with a camera, an image is obtained, which is integrated over the exposure time and averaged in the process.

In the case of harmonic oscillations, with integration times of a full oscillation period or a multiple thereof, this averaging leads to an amplitude-dependent reduction of the line, or interference, contrast corresponding to a zero order Bessel function. Various methods are known for measuring and displaying images of this contrast reduction, which oscillates as a function of the amplitude. Although

it is possible with this to obtain a visual impression of the oscillation forms of the surface, at least in connection with simple modes, and in particular to detect the position of the nodal lines, a point-by-point measurement of the oscillation amplitude is not possible because of the oscillating character of the Bessel function.

### **SUMMARY OF THE INVENTION**

One object of this invention is to provide a measuring method which permits a quantitative evaluation of the chronologically changing line images with the aim of a point-by-point amplitude determination. Two variations were developed for this, which are disclosed in the following specification and in the claims.

With the first method, a special stroboscopic recording technique is used, which is particularly suited for oscillating objects. It is necessary during one oscillation to keep the exposure time sufficiently short in order to prevent a significant displacement of the line images during this period of time. Stroboscopic methods based on a synchronization of the illumination have long been known. Pulsed light sources, or light sources with optical components attached in front of them, for example, are used for this purpose, whose degree of transmission is chronologically varied. However, many of these methods have disadvantages in price and/or technology. For example, if pulsed lasers are used, the emission output must be sufficiently high to guarantee sufficient illumination. Most of these systems are expensive and can be employed only in a limited way because of laser protection

regulations. The customary employment of chopper wheels has several disadvantages, such as their space requirements and the necessity of the mechanical decoupling of the chopper movement from the object oscillation.

Several cameras are commercially available which permit sufficiently short exposure times, so that the surface movement during the exposure time is negligible. If very high emission outputs cannot be used, however, these exposure times are not sufficient for obtaining a high-contrast image. Therefore, after exposure it would be necessary to read the image out into an image storage device, subsequently to make further recordings, each in the same oscillation state, and to add together a sufficient number of these images in the storage device so that a sufficient contrast exists. But since reading the images out would take a long time, this method cannot be employed in actual practice.

To avoid reading out partial images, a camera with a special recording chip is used in connection with the method of this invention. This component makes it possible to use the shift register of the recording sensor, which is intended for reading out the image information, as an intermediate storage device for the image information. The image information received during the period of time not of interest can, by appropriate electronic wiring, be left out of consideration in this component. A short-time recording is again made in the next time period of interest and is subsequently superimposed on the previous recording in the shift register. Once a

sufficient number of short-time recordings have been superimposed on each other, the high-contrast image is read out in only one read-out cycle. With this it is possible to omit a time-consuming readout and summing up of individual images in a separate storage device.

With the second measuring method, the recording of the image is performed with the aid of the electronic shutter of the camera over one or several full oscillation periods. It is then possible with the aid of the known phase-shift method to determine, as well as average, the interference amplitude and phase, for the interferometric methods, or the line amplitude and phase, for each pixel over the course of a full oscillation at rest. In the case of harmonic oscillations, with increasing oscillation amplitude averaging results in a decrease of the interference amplitude in accordance with a zero order Bessel function, and with an unchanged interference phase in the positive value range of the Bessel function, and with a phase reversal in the negative value range. If the amplitude of the excitation is changed by known steps, rightly assuming a linear response behavior at each pixel, a corresponding step-by-step change of the local oscillation amplitude results, and therefore a change of the measured chronologically averaged interference amplitudes and phases in accordance with the above described Bessel function. It is possible by an adaptation of the parameter of the Bessel function to the measured amplitude and phase values to determine the function which best describes the sequence of the

measuring points. The parameter determined in this way is a measurement for the relative excitation of the surface at this location.

If the surface movement is composed of a deformation portion and a superimposed translatory and/or rotatory displacement portion, the deformation portion can be determined, for example, by simultaneous or sequential comparison measurements, or on the basis of the behavior in connection with different excitation patterns.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

This invention will be explained in greater detail by exemplary embodiments represented in the drawings wherein:

Fig. 1 is a schematic representation of a first measuring arrangement;

Figs. 2a, and 2b1 to 2b3, show various representations of an image recording sensor and its function;

Fig. 3 is a schematic representation of a further measuring arrangement;

Figs. 4a and 4b show chronological sequences for the excitation of the surface and the creation of summed images; and

Fig. 5 is a representation of the measured phase shift as a function of the excitation frequency.

## **DESCRIPTION OF PREFERRED EMBODIMENTS**

Fig. 1 represents a typical arrangement of the line projection method in accordance with this invention. A light source 1 illuminates a grating 2, which is cast through an imaging element 3 onto an object surface 5. The line image on the surface 5 is represented by means of an imaging system 8 on a recording sensor 9 in the form of a camera chip. An optical axis 6 of the illuminating device is tilted at an angle 4 with respect to an optical axis 7 on a recording group. A frequency generator 11 is set by a central control unit 10.

At the start of a recording averaged from individual images, the central control unit 10 initializes an electronic triggering device 12, which makes the required clock and control signals for the recording sensor 9 available. The frequency generator 11 is subsequently started. An actuator 13, which excites the surface 5 by means of the set frequency, is operated by means of the output signal from the frequency generator 11. The image recordation is controlled by means of the electronic triggering device 12 synchronously in such a way that the respective actual image information is only obtained in a very small time window. An additional phase setter 14 is provided to record the oscillations in various phase states between the object excitation and the image recordation. The image summed up in the recording sensor 9 is subsequently read out into an external image storage device 15 and is evaluated.



Often several recordings of the same deformation state are made for a simpler and more accurate determination of the position and displacement of the lines in the image, and the position of the grating 2 is displaced between these recordings by a fixed fraction of the gratings constant, according to a phase shifting method. The additional setting unit 22, which is also triggered by means of the electronic triggering device 12, is used for this purpose.

If the lines projected by the grating 2 are not recorded directly, but by the superimposition of the lines of a further grating, this is a moiré line projection method, for example.

Fig. 2 shows an embodiment of the recording sensor 9. The image recordation by means of sensor elements 16 for image recording, the so-called pixels, is performed during a short period of time (Fig. 2b1) in that charged particles 17 are collected. Thereafter, the charge package 17 thus generated is transferred into a shift register 18 in that the potential wall between the pixel and the shift register is reduced by applying an appropriate control voltage to a control electrode 19, via the electronic control device 12 (Fig. 2b2). Then the potential at the control electrode 19 is reduced again, and the potential at the second control electrode 20 is reduced for the next time interval. Because of this the charge generated in the pixel flows off via the overflow register 21 during this period of time (Fig. 2b3). The control electrode 20 is set back again for the next partial recording, so that the state again corresponds to Fig. 2b1.

Fig. 3 shows a modified arrangement such as can be used in accordance with the claims for the so-called ESPI method. A laser 25 is used as the light source. The laser beam is widened by means of a semi-reflecting mirror 26, a mirror 27 and an optical expansion device 28 in such a way that the object surface 5 is completely illuminated. Structural elements of the surface 5 reflect a portion of these emissions. A portion is represented on the recording sensor 9 via the imaging system 8 in the form of a lens. The so-called speckles are generated on the recording sensor 9 through the diaphragm of the imaging system 8. The second partial beam generated at the semi-reflecting mirror 26 is sent through a phase-setting unit 29, a further mirror 30, a reproducing unit 31 and a semi-reflecting mirror 32 to be represented in the imaging system 8 and thus is superimposed on the speckle image of the first partial beam. If approximately equal optical path lengths of 26 - 27 - 28 - 5 - 32 for the first partial beam, and 26 - 29 - 30 - 31 - 32 for the second partial beam are maintained, the two partial beams generate an interference image on the recording sensor 9, wherein the intensity measured in each sensor element 16 is determined by the respective phase difference between the two partial beams.

If the position or shape of the surface is changed via the actuator 13, the phase difference changes correspondingly. As explained in Fig. 2, the averaged recordings are generated by summing the charge packages 17 in the shift register 18 of the recording sensor 9 synchronously with the movement of the surface 5. By

means of the optical phase setting unit 29 it is possible to vary the phase of a partial beam between these averaged recordings by a fixed fraction of the wavelength. The speckle contrast is correspondingly changed. This method corresponds to the displacement of the grating 2 by means of the additional setting unit 22 in the first example. Therefore the analysis of the images takes place correspondingly.

Figs. 4a and 4b represent an example shown in claim 3. Fig. 4a shows the chronological sequence of the excitation of the surface 5 by the actuator 13. The selected fixed phase positions 35 to 38 are drawn, corresponding to which the respective summed images are recorded. The first summed image is recorded in the phase position 35, the second in phase position 36, etc. At any arbitrary point, the surface performs the same movement, but with a different amplitude and phase shift. The phase shift 39 and amplitude 40 (Fig. 4b) can be calculated for each pixel from the four summed images.

Fig. 5 shows an example wherein with the excitation amplitude fixed, the surface 5 is examined by means of the actuator 13 (Figs. 1, 3), and the phase shift 39 (Fig. 4) is determined for each point of the surface. The measured phase shift 39 changes with a change of the excitation frequency. Conclusions regarding the resonance frequency can be drawn from an analysis of this course.

Figs. 1 and 3 show one embodiment of this invention. However, a conventional camera, which does not meet the requirements of the special read-out

and intermediate storage method shown in Fig. 2, could also be used for recording images. Also, cameras using film would be conceivable, but would make little sense for rapid evaluation. The difference from the methods described above is that exposure is made over a longer period of time, so that the surface is displaced by a definite amount during this period of time. If, for example, the speckle arrangement in accordance with Fig. 3 is selected, and the exact chronological length of a period of the surface excitation as the exposure time, an averaged speckle interference amplitude is detected by the camera. This interference amplitude is reduced with an increased oscillation amplitude of the surface. This reduction as a function of the amplitude can be described by means of a zero order Bessel function. As a rule, the deflections at some points are already known, such as fastening points with zero deflection, and excitation points having the induced excitation amplitude. The respective deflection can be determined from a comparison of the measured interference amplitude over the surface with the Bessel function.

Evaluation becomes simpler if the interference amplitude for each surface point is sequentially determined for several excitation amplitudes. If the interference amplitude at one point on the surface is examined as a function of the excitation strength, the course of the Bessel function can be directly read out.